Status Report of the DIRAC Experiment - PS 212

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SPSC, October 2017
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Santiago de Compostela University
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Bern University
Bern, Switzerland

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1. Experimental check of QCD using $\pi^+K^-$, $\pi^-K^+$ and $\pi^+\pi^-$ atoms.

2. $\pi^+K^-$ and $\pi^-K^+$ atoms status

3. Long-lived $\pi^+\pi^-$ atom lifetime first measurement.


5. Short-lived $\pi^+\pi^-$ atoms analysis.

6. The new physical method to investigate the particle production in the coordinate space.

7. $K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$ and $K^+K^-$ atom production at SPS CERN
Fig. 2. General view of the DIRAC setup:
1 -- target station with insertion, showing the Be target, magnetic field and Pt breakup foil; 2 -- first shielding; 3 -- microdrift chambers (MDC); 4 -- scintillating fiber detector (SFD); 5 -- ionisation hodoscope (IH); 6 -- second shielding; 7 -- vacuum tube; 8 -- spectrometer magnet; 9 -- vacuum chamber; 10 -- drift chambers (DC); 11 -- vertical hodoscope (VH); 12 -- horizontal hodoscope (HH); 13 -- aerogel Cherenkov; 14 -- heavy gas Cherenkov; 15 -- nitrogen Cherenkov; 16 -- preshower (PSh); 17 -- muon detector.
(The plotted symmetric and asymmetric events are a $\pi^+\pi^-$ and $K^+\pi^-$ pair, respectively.)
\[ \frac{1}{\tau} = R \left| a_{1/2} - a_{3/2} \right|^2 \]

\[ \tau_{th} = (3.5 \pm 0.4) \times 10^{-15} \text{ s}. \] The evaluation error from this relation for \( \left| a_{1/2} - a_{3/2} \right| \) is 1%.
The QCD Lagrangians use the $SU(3)_L \times SU(3)_R$ and $SU(2)_L \times SU(2)_R$ chiral symmetry breaking.

$\mathcal{L}(u,d,s) = \mathcal{L}(3) = \mathcal{L}_{\text{sym}}(3) + \mathcal{L}_{\text{sym.br.}}(3)$

$\mathcal{L}(u,d) = \mathcal{L}(2) = \mathcal{L}_{\text{sym}}(2) + \mathcal{L}_{\text{sym.br.}}(2)$

$\mathcal{L}_{\text{sym.br.}}$ is proportional to $m_q$

$e^+e^- \rightarrow \text{hadrons}$

QCD provides cross sections with 1% precision

1. Perturbation theory is working at high momentum transfer $Q$.
2. Unitarity condition.

At large $Q$, contribution of $\mathcal{L}_{\text{sym.br.}}$ to the cross section is proportional to $1/Q^4$.

Therefore these experiments checked only the $\mathcal{L}_{\text{sym}}$ prediction precision.

To check the total $\mathcal{L}(3)$ Lagrangian predictions, we must study the low momentum transfer $Q$ processes.

**Tools:** Lattice calculations and Chiral Perturbation Theory (ChPT)

Lattice----- $\mathcal{L}(3), \mathcal{L}(2)$

ChPT-------Effective Lagrangians.
The $S$-wave $\pi K$ scattering lengths $a_{1/2}$ and $a_{3/2}$ in the chiral symmetry world are zero. Therefore the scattering length values $a_{1/2}$ and $a_{3/2}$ are very sensitive to the $\mathcal{L}_{\text{sym.br.}}(3)$.

For Lattice QCD the $\pi K$ interaction at threshold is a relatively simple process. It gives $\pi K$ scattering length values with an average precision of 5%. This precision will be improved in the near future.

There is only one experimental data: DIRAC collaboration observed $349\pm62$ $\pi K$ atomic pairs ($\text{Phys.Rev.Lett.} 2016$) and measured $|a_{1/2}-a_{3/2}|$ with an average precision of 34% ($\text{Phys.Rev.D} 2017$).
DIRAC setup, experimental and theoretical data

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Detected atomic pairs ($n_A$)</th>
<th>$\tau$ (10^{-15} sec)</th>
<th>$\alpha^- = \frac{1}{3} (a_{1/2} - a_{3/2})$</th>
<th>Average error</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIRAC</td>
<td>$349\pm61$ (stat)±9 (syst) = $349\pm62$ (tot) (5.6$\sigma$)</td>
<td>$5.5^{+5.0}_{-2.8}$</td>
<td>$0.072^{+0.031}_{-0.020}$</td>
<td>34%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Theory</th>
<th>$\alpha^-$</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.Buttiker et al., Eur.Phys.J. (2004)</td>
<td>0.090±0.005</td>
<td>Roy-Steiner equations</td>
</tr>
<tr>
<td>K.Sasaki et al., Phys.Rev. (2014)</td>
<td>0.081</td>
<td>Lattice calculations</td>
</tr>
<tr>
<td>Z.Fu, Phys.Rev. (2013)</td>
<td>0.077</td>
<td>Lattice calculations</td>
</tr>
<tr>
<td>C.Lang et al., Phys.Rev. (2012)</td>
<td>0.10</td>
<td>Lattice calculations</td>
</tr>
<tr>
<td>J.Bijnens et al., J. High Energy Phys. (2004)</td>
<td>0.089</td>
<td>ChPT, two loops</td>
</tr>
</tbody>
</table>

27 September to 19 November.
The DIRAC collaboration [Phys. Lett. (2015)] observed $436 \pm 61$ pion pairs from the long-lived ($\tau \geq 1 \times 10^{-11}$ sec) $\pi^+ \pi^-$ atom breakup in Pt foil [Phys. Lett. (2015)].

The short-lived atoms lifetime measurement allowed to evaluate $\pi\pi$ scattering length combination $a_0 - a_2$. The study of the long-lived atoms will allow to measure the Lamb shift depending on another $\pi\pi$ scattering length combination: $2a_0 + a_2$ and to evaluate the $a_0, a_2$ separately.
Fig. 1 Method to observe long-lived $A_{2\pi}^{L}$ by means of a breakup foil ($Pt$). The most of the produced $\pi^+\pi^-$ atoms decay (~70%) or are ionized (~6%) in the $Be$ target. The excited (long lived) atoms (~24%) are investigated here.
<table>
<thead>
<tr>
<th>$n$</th>
<th>$\tau_{2\pi}$ (10^{-11} \text{sec})</th>
<th>s ($l=0$)</th>
<th>p ($l=1$)</th>
<th>s ($l=0$)</th>
<th>p ($l=1$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$2.9 \cdot 10^{-4}$</td>
<td>-</td>
<td>1.39 $\cdot 10^{-3}$</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$2.32 \cdot 10^{-3}$</td>
<td>1.17</td>
<td>1.11 $\cdot 10^{-2}$</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$7.83 \cdot 10^{-3}$</td>
<td>3.94</td>
<td>3.76 $\cdot 10^{-2}$</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$1.86 \cdot 10^{-2}$</td>
<td>9.05</td>
<td>8.91 $\cdot 10^{-2}$</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$3.63 \cdot 10^{-2}$</td>
<td>17.5</td>
<td>1.74 $\cdot 10^{-1}$</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$6.26 \cdot 10^{-2}$</td>
<td>29.9</td>
<td>3.01 $\cdot 10^{-1}$</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>$9.95 \cdot 10^{-2}$</td>
<td>46.8</td>
<td>4.77 $\cdot 10^{-1}$</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>$1.48 \cdot 10^{-1}$</td>
<td>69.3</td>
<td>7.13 $\cdot 10^{-1}$</td>
<td>333</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 6. $|Q_L|$ distribution of $\pi^+\pi^-$ pairs for $Q_T<2.0$ MeV/c

Fig. 7. $Q_T$ distribution of $\pi^+\pi^-$ pairs for $|Q_L|<2$ MeV/c

a) Experimental distribution (points with statistical error) and the simulated background (solid line).
b) Experimental distribution after background subtraction (points with statistical error) and the simulated distribution of atomic pairs (dotted-dashed line). The fit procedure has been applied to the 2-dimensional ($|Q_L|, Q_T$) distribution.
Number of atoms generated on Be target: \( N_A = 16960 \pm 290 \text{tot} \)

Number of long-lived atoms after Be target: \( N_A^{\text{L,Be}} = 1153 \pm 104 \text{tot} \)

Number of atoms entered Pt foil: \( N_A^{\text{L,Pt}} = 501^{+184}_{-80} \text{tot} \)

Number of atomic pairs after Pt foil: \( n_A = 436 \pm 157 \text{tot} \)

The lifetime of long-lived atom in simple approach:

\[
\tau_L = \left( 1.21 \pm 0.19 \right)_{\text{stat}} \left( ^{+0.75}_{-0.18} \right)_{\text{syst}} \times 10^{-11} = 1.21^{+0.77}_{-0.26} \text{tot} \times 10^{-11} \text{s}
\]

QED: \( \tau_{2p} = 1.17 \times 10^{-11} \text{s} \)

The measured ground state lifetime: \( \tau_{1s} = 3.15^{+0.28}_{-0.26} \text{tot} \times 10^{-15} \text{s} \)
**K⁺K⁻ pair analysis**

Search for the $K^+K^-$ Coulomb pairs signal

Distribution of $K^+K^-$ pairs in the RUN 2010 over the full pair momentum in laboratory system.

For the $K^+K^-$ Coulomb pair signal analysis it was selected pairs with low lab. momentum $2.6<P<4.0$ GeV/c and high lab. momentum $6<P<10$ GeV/c. In these two intervals the level of the background is relatively small (see the error bar values).
Fig. 6. Experimental distributions of selected events. Events are fitted by the simulated distribution of $K^+K^-$ pairs (red) and experimental distribution of pure $\pi^+\pi^-$ (blue) processed with kaon masses. The number of $K^+K^-$ pairs is $2180 \pm 200$, the number of $\pi^+\pi^-$ pairs is $1340 \pm 200$. 

10/16/2017
1. $2180 \pm 200$ $K^+K^-$ pairs with $Q_T < 6$ MeV/c were identified in the RUN 2010. The total number of $K^+K^-$ pairs with $Q_T < 6$ MeV/c after processing of all statistics is expected to be about 4000 events.

2. The number of produced $K^+K^-$ atoms and upper limit of their lifetime will be evaluated for the first time from the number of $K^+K^-$ Coulomb pairs with small relative momentum in their center of mass.

3. The simulation of $K^+K^-$ atoms yield and spectrum using CERN version of FRITIOF generator for proton momentum 24 GeV/c and 450 GeV/c is finished.

4. Results of $K^+K^-$ pairs investigation will be finished and published in 2018.
In 2018, DIRAC will perform a search for proton-antiproton Coulomb pairs and thus proton-antiproton atoms with the same strategy as in the $K^+K^-$ case. Investigation results will be published in 2019.
$Q_i$ for $Q_T$ between 0-1 MeV (accidentals subtracted) MeV/c
Coulomb correlations as a possible new physical method to investigate the particles production in the coordinate space.

The shape of Coulomb correlation curve for $K^+K^-$ and proton-antiproton pairs is expected to be much sensitive to the size of particle production region compared to the case of $\pi^+\pi^-$ pairs. Thus, detailed study of this shape could open a possibility to evaluate the size of production region for such pairs. The investigation is planned for 2018.
Coulomb correlations with account of size of pair production region $r^*$

$$A_c(r^*, a_B) = A_c(0) \left[ 1 - \frac{2r^*}{a_B} + \cdots \right]$$

Point-like Coulomb correlation
Experimental results

\( K \rightarrow 3\pi \)

(scattering length in \( m_\pi^{-1} \))

2009 NA48/2 (EPJ C64, 589)

\[ a_0 - a_2 = 0.2571 \pm 0.0048 \pm 0.0025 \pm 0.0014 \pm 2.2\% \]

plus additional 3.4\% theory uncertainty

Ke4:

2010 NA48/2 (EPJ C70, 635)

\[ a_0 = 0.2220 \pm 0.0128 \pm 0.0050 \pm 0.0037 \pm 6.4\% \]

\[ a_2 = -0.0432 \pm 0.0086 \pm 0.0034 \pm 0.0028 \pm 22\% \]

\( \pi^+ \pi^- \) atom:

2011 DIRAC (PLB 704, 24)

\[ |a_0 - a_2| = 0.2533 \pm 0.0078 \pm 0.0072 = +4.2\% \]

\[ +0.0072 \]

\[ -0.0080 \]

\[ |a_0 - a_2| = 0.2533 \pm 0.0078 \pm 0.0077 = -4.4\% \]
III. The short-lived $\pi^+\pi^-$ atom lifetime measurement

Preliminary results on the short-lived atom lifetime measurement based on all available 2008-2010 data are presented in Fig. 1 and 2.

Fig. 1. Distribution over $|Q_L|$ for events, selected with criterion $Q_T < 4\text{ MeV/c}$. Fractions of atomic, Coulomb and non-Coulomb pairs were obtained by fitting the distribution over $(|Q_L|, Q_T)$ with criteria: $|Q_L| < 15\text{ MeV/c}$, $Q_T < 4\text{ MeV/c}$.

$N_A = 51091. \pm 214.$
$n_A = 24226. \pm 444.$
$P_{Br} = 0.474 \pm 0.010$
1. The average probability of $\pi^+\pi^-$ atom breakup for the Ni targets of 98 µm thickness (RUN 2008) and 109 µm (RUNS 2009-2010) was evaluated as $P_{br} = 0.474 \pm 0.01$. It is in agreement with the value $P_{br} = 0.46 \pm 0.013$ obtained for the 98 µm target and published in 2011. In the final data analysis, the new measurements of multiple scattering will be included. The dedicated paper will be ready before June of 2018.

2. The current value of systematical error in the $\pi^+\pi^-$ atom lifetime measurement is equal to the statistical uncertainty. The main part of the systematical error arises due to an uncertainty in the multiple scattering in the Ni target. To reduce this error, we did an experimental study of the multiple scattering in the targets: Be: 100 and 2000 µm; Ti: 250 µm; Ni: 50, 109 and 150 µm and Pt: 2 and 30 µm. For Be (2000 µm), Ni (109 µm) the difference between theoretical and experimental r.m.s. is 0.4% and 0.8% accordingly. The r.m.s. values were calculated in the interval of $\pm 2\sigma$. The achieved precision of multiple scattering investigation is better by one order of magnitude than in the previous experiments.
Simultaneously the expected number of $\pi^+\pi^-$ atomic pairs $n_A=400000$. The statistical (systematic) precision of the $\pi^+\pi^-$ scattering length will be: 0.7% (2%).
1. Production of Coulomb $K^+K^-$ pairs, evaluation of the correspondent number of produced $K^+K^-$ atoms and upper limit of their lifetime will be published for the first time.

2. The measurement of the long-lived $\pi^+\pi^-$ atom lifetime will be finished and published.

3. The measurement of the short-lived $\pi^+\pi^-$ atom lifetime and $\pi\pi$ scattering length will be finished and published.

4. To search for the Coulomb proton-antiproton pairs.

5. To investigate the possibility of using the Coulomb correlations in $K^+K^-$ and proton-antiproton pairs as a new physical tool to study the particles production in the coordinate space.

6. To measure the multiple scattering in thin layers of 4 materials with the precision better by one order of magnitude than in the previous experiments.

7. To prepare the LOI for hadronic atoms study at SPS CERN to check the low-energy QCD predictions.
Thank you
Additional slides
For charged pairs from short-lived sources and with small relative momenta $Q$, Coulomb final state interaction has to be taken into account. This interaction increases the production yield of the free pairs with $Q$ decreasing and creates atoms.

There is a precise ratio between the number of produced Coulomb pairs ($N_C$) with small $Q$ and the number of atoms ($N_A$) produced simultaneously with Coulomb pairs:

$$N_A = K(Q_0)N_C(Q \leq Q_0), \quad \frac{\delta K(Q_0)}{K(Q_0)} \leq 10^{-2}$$

$n_A$ - atomic pairs number, $P_{br} = \frac{n_A}{N_A}$
<table>
<thead>
<tr>
<th>n</th>
<th>l</th>
<th>m</th>
<th>$\pi^+\pi^-$ atom distrib.(%)</th>
<th>$\sum_m$ (%)</th>
<th>$\sum_{l,m}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>11.66</td>
<td>11.66</td>
<td>11.66</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>3.58</td>
<td>3.58</td>
<td>6.07</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0.67</td>
<td>0.67</td>
<td>2.23</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0.19</td>
<td>0.19</td>
<td>1.10</td>
</tr>
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<td>5</td>
<td>0</td>
<td>0</td>
<td>0.041</td>
<td>0.041</td>
<td>0.75</td>
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<td>6</td>
<td>0</td>
<td>0</td>
<td>0.044</td>
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<td>0.68</td>
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<tr>
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<td>0.028</td>
<td>0.28</td>
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<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0.025</td>
<td>0.025</td>
<td>0.25</td>
</tr>
</tbody>
</table>

TOTAL SUM: 24.19%
$Q_y$ distribution of “atomic pairs” (signal) above the background of $\pi^+\pi^-$ Coulomb pairs produced in Beryllium target, without (left) and with (right) magnet used in 2012 run.

Selected events with the cut: $\sqrt{Q_x^2 + Q_y^2} < 2\text{MeV} / c$

Expected signal (atomic pairs) from broken up long-lived $\pi^+\pi^-$ atoms

Simulation without magnet  
Simulation with magnet
The time-of-flight distribution for the low momentum interval

The time-of-flight distribution for the high momentum interval
The $A_{2K}$ lifetime is strongly reduced by strong interaction (OBE, scalar meson $f_0$ and $a_0$) as compared to the annihilation of a purely Coulomb-bound system ($K^+K^-$).

<table>
<thead>
<tr>
<th>$\tau (A_{2K} \rightarrow \pi\pi,\pi\eta)$</th>
<th>$K^+K^-$ interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.2 \times 10^{-16}$ s [1]</td>
<td>Coulomb-bound</td>
</tr>
<tr>
<td>$8.5 \times 10^{-18}$ s [3]</td>
<td>momentum dependent potential</td>
</tr>
<tr>
<td>$3.2 \times 10^{-18}$ s [2]</td>
<td>+ one-boson exchange (OBE)</td>
</tr>
<tr>
<td>$1.1 \times 10^{-18}$ s [2]</td>
<td>+ $f'_0$ (I=0) + $\pi\eta$-channel (I=1)</td>
</tr>
<tr>
<td>$2.2 \times 10^{-18}$ s [4]</td>
<td>ChPT</td>
</tr>
</tbody>
</table>

References:
I. Long-lived states of $\pi^+\pi^-$ atoms

Fig. 3. Experimental distribution of the $\pi^+\pi^-$ pairs over $Q_Y$. Data selected with criteria $|Q_X|< 2 \text{ MeV/c}$ and $|Q_L|< 2 \text{ MeV/c}$.

The indicated peaks are due to $\pi^+\pi^-$ pairs produced in the Pt foil and Be target.

Fig. 4. Ratio of the prompt to accidental $\pi^+\pi^-$ pairs over $Q_Y$ projection.

Top: Experimental distribution, the peak at $Q_Y=13.15 \text{ MeV/c}$ corresponds to the Coulomb pairs produced in the Be target.

Bottom: Simulated distribution.
I. Long-lived states of $\pi^+\pi^-$ atoms

Fig. 5. a) Experimental distribution of $\pi^+\pi^-$ pairs (points with error bars) for the Beryllium ($Be$) target fitted by a sum of simulated distributions of “atomic”, “Coulomb” and “non-Coulomb” pairs. The background distribution of free (“Coulomb”, “non-Coulomb”) pairs is shown as black line.
b) Difference distribution between the experimental and simulated free pair distributions compared with the simulated distribution of “atomic pairs”
Fig. 8. $|Q_L|$ experimental distribution after subtraction of background obtained with 3 parameter fit (black points with statistical error) and after subtraction of background obtained with 2 parameter fit (blue dashed line), comparing to the simulated distribution of atomic pairs (red dotted-dashed line). The fit procedures have been applied to the 1-dimensional $|Q_L|$ distribution. The atomic pairs number in the region $|Q_L| < 2$, $Q_T < 4$ MeV/c obtained with 3 parameter fit is $n_A^L = 435\pm03$ and with 2 parameter fit is $n_A^L = 579\pm64$. 

I. Long-lived states of $\pi^+\pi^-$ atoms
III. The short-lived $\pi^+\pi^-$ atom lifetime measurement

Preliminary results on the short-lived atom lifetime measurement based on all available 2008-2010 data are presented in Fig. 1 and 2.

Fig.2. Distribution over $Q_T$ of events, selected with criterion $|Q_L| < 2$ MeV/c. Fractions of atomic, Coulomb and non-Coulomb pairs were obtained by fitting the distribution over $(|Q_L|, Q_T)$ with criteria: $|Q_L|<15$ MeV/c, $Q_T < 4$ MeV/c. $N_A$, $n_A$ and $P_{br}$ are the number of produced atoms, detected atomic pairs and probability of the atoms breaking in the target respectively.
α_s large – small $Q^2$
“quark confinement”
perturbative QCD not suitable.
Lattice QCD solve field equations on a space-time lattice by MC.

α_s small – large $Q^2$
“asymptotic freedom”
and perturbative QCD

String breaks generate $q\bar{q}$ pair to reduce field energy

π^+

u \bar{d}

Small $\Delta x$ distance; quark degrees of freedom

“asymptotic freedom”

π^+

u \bar{d}

Energy fed into the system

π^0

π^+

u \bar{u} \bar{u} \bar{d}

Large $\Delta x$ distance; pion degrees of freedom

“quark confinement”

DIRAC

S. Bethke,
## DIRAC++ (Detectors)

<table>
<thead>
<tr>
<th>Setup element (number planes)</th>
<th>Aperture (cm)</th>
<th>Occupancy ($s^{-1} \cdot cm^{-2}$)</th>
<th>$X_0$ %</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Coordinate (µm)</td>
</tr>
<tr>
<td>1. Target Station (*)</td>
<td>7.6 × 7.6</td>
<td>(5 ÷ 20) · 10⁵</td>
<td>0.7 ÷ 1.5</td>
<td>50</td>
</tr>
<tr>
<td>2. Vacuum system (*)</td>
<td>9.0 × 9.0</td>
<td>(4 ÷ 16) · 10⁵</td>
<td>&lt; 5</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>3. Vertex detector (2 ÷ 4 planes)</td>
<td>10. × 10.</td>
<td>(3 ÷ 12) · 10⁵</td>
<td>2.7</td>
<td>60</td>
</tr>
<tr>
<td>4. RICH?</td>
<td>155 × 50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. SFD (3 planes) (*)</td>
<td>75 ÷ 110×44</td>
<td>(1 ÷ 10) · 10⁴</td>
<td>4 ÷ 8</td>
<td>&lt; 80</td>
</tr>
<tr>
<td>6. Vacuum system (*)</td>
<td>112 × 44</td>
<td>(1 ÷ 8) · 10⁴</td>
<td></td>
<td>&lt; 0.7</td>
</tr>
<tr>
<td>7. Iron shielding wall (*)</td>
<td>115 × 44</td>
<td>(1 ÷ 8) · 10⁴</td>
<td></td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>8. Spectrometer magnet (*)</td>
<td>30 × 49</td>
<td>(1 ÷ 8) · 10⁴</td>
<td></td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>9. Downstream Tracker (2 × 8)</td>
<td>90 × 50</td>
<td>(1 ÷ 10) · 10³</td>
<td></td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>10. Vertical Hodoscope (2 × 1 ÷ 2) (*)</td>
<td>37 × 53</td>
<td>(1 ÷ 8) · 10⁴</td>
<td></td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>11. Horizontal Hodoscope (2) (*)</td>
<td>148 × 60</td>
<td>(1 ÷ 8) · 10³</td>
<td></td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>12. Heavy Gas Cherenkov detector (2) (*)</td>
<td>56 × 60</td>
<td>(5 ÷ 40) · 10³</td>
<td></td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>13. Nitrogen Cherenkov detector (2)</td>
<td>10. × 10.</td>
<td>(4 ÷ 16) · 10⁵</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

* - Existing parts of the Setup

? - Micro-Pattern Gas Detectors (MPGD)
The data at $p_p = 24\text{GeV/c}$ and $450\text{GeV/c}$ were simulated, processed and analysed (V. Yazkov, DIRAC note, 2016 05).

**Experimental conditions on SPS with Ni target**

Thin Ni target, nuclear efficiency $\sim 6\times 10^{-4}$.

The proton beam can be used for other experiments.

Proton beam intensity: $3\times 10^{11}$ protons/s  
(DIRAC worked at $2.7\times 10^{11}$ protons/s)

Number of spills: $4.5\times 10^5$ with spill duration 4.5 s

Data taking: 3000 spills per 24 hours.

Running time: 5 months

<table>
<thead>
<tr>
<th>The expected number of $\pi K$ atomic pairs: $n_A=13000$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(In the DIRAC experiment was $n_A=349\pm62$)</td>
</tr>
</tbody>
</table>

The statistical precision in these conditions for $\pi K$ scattering length will be: $\sim5\%$

The expected systematic error will be at the level of $2\%$

The expected number of $\pi^+\pi^-$ atomic pairs $n_A=400000$

The statistical precision of the $\pi^+\pi^-$ scattering length will be: $0.7\%$

The expected systematic error will be at the level of $2\%$
- The QCD Lagrangian $\mathcal{L}(2)$ and Chiral Lagrangian describe processes with $u$ and $d$ quarks, using $SU(2)_L \times SU(2)_R$ chiral symmetry breaking.

- From the ChPT prediction for $a_0$ and $a_2$, the $\pi^+\pi^-$ atom lifetime in the ground state, given by $1/\tau = R|a_0-a_2|^2$, is $\tau_{th}=(2.9\pm0.1) \times 10^{-15}$ s.

- The evaluation error for $|a_0-a_2|$ from this relation is 0.6%.

- These Lagrangians predict the S-wave $\pi^+\pi^-$ scattering lengths $a_0$ and $a_2$. 
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$a_2$</td>
<td>~1% precision</td>
<td></td>
</tr>
<tr>
<td>ChPT</td>
<td>$a_0$ and $a_2$</td>
<td>2.3% precision</td>
<td>Colangelo et al. Nucl. Phys. (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5% precision</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$a_0-a_2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>on SPS</td>
<td>$a_0-a_2$</td>
<td>~2% precision</td>
<td>DIRAC estimation</td>
</tr>
</tbody>
</table>